Urban traffic model for simulators

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Abstract

This work describes the development of a traffic model for simulators of vehicles, pedestrians, traffic signs and traffic lights within an urban environment. The model must optimize its capacities between difficult and opposing requirements such as the mandatory nature to produce results in real time, the high number of vehicles and pedestrians that must be simultaneously simulated, the most realistic reproduction of the vehicle’s physical behaviour, the development of a driver behaviour model and the traffic light control. In order to conciliate all these requirements several lines of action have been taken simultaneously, such as the simplified and ordered representation of the lanes that make up streets and traffic islands, keeping interactions between drivers to the minimum, reducing the physical model of a vehicle to what is necessary for realistic driving and splitting the urban environment into zones. Additionally, several methods have been contemplated to produce traffic incidents, obstacles and obstructions that provide urban traffic with greater realism. The model thus obtained has its immediate application in training simulators, such as one that is being developed at the moment to train bus drivers in Madrid, and is also applicable to studies of traffic control by means of traffic lights, or studies of the impact caused by planning changes to city roads.

1 Introduction

The use of traffic simulators is today out of any doubt for driver training tasks in wide range of civil driving activities [6,7,8]. Although the first use of traffic simulators is for urban design and traffic control [2,5].

The principal component of an urban traffic simulator is the traffic model. There are two principal philosophies for modelling the traffic microscopic and macroscopic. In the first one each vehicle is modelled individually along with the
rest of details of the traffic like signals, pedestrians etc [2]. The macroscopic philosophy [5], takes account of the traffic in terms of global flows, generally with a pseudo hydraulic approximation, where individual vehicles lose their identity and the details of traffic are introduced like parameters that modify the flow.

For drivers training purposes it is necessary a realistic behaviour and visual aspect of the individual vehicles that surround the user vehicle. Therefore only the microscopic approach is suitable for this target. It is also necessary the real time feature in the traffic model.

A microscopic urban traffic model is formed by several sub models for drivers, vehicles, pedestrians, traffic lights, passive signalling and city description. The rest of component of the simulator are constituted by the input and output physical interfaces, in different levels of realism, and the instructor tools.

In the following sections will be described the different models and elements that compound the global urban traffic models.

2 Principal models

2.1 Driver model

The driver model is intended to simulate the human driver behaviour. It must determine the vehicle speed and directional control, as well as the behaviour relative to signalling and the way to follow in the city. The driver model developed is a variant of the car-following theory used habitually [9].

The desired way is determined by a set of trajectories that represent the lane middle line. These trajectories are formed by sequences of straight lines and arcs. Each one of these elements has information about the geometry and major speed associated to the trajectory. Each trajectory is linked with another, thus generating all the possible paths. The driver will select a certain path based on the probability associated to each connectivity in a crossing. The driver model selects in real time the connectivity for the next trajectory in the nearby of the end of the current trajectory.

The speed will be determined by the trajectory characteristics, the speed of the previous vehicle, the signalling and, in the case of being in the surroundings of a crossing, the speed and positioning of all the vehicles inside the crossing that can collide with it.

For the directional control, the driver model will try to arrive in every moment at a point located at a distance $d$ ahead of the vehicle, figure 1. The vehicle model is controlled by the manoeuvres over the steering wheel and brake and accelerator pedals. Due to the fact that the model is dynamic, a very precise control of the manoeuvres carried out by the driver is necessary in order to guarantee the stability and response speed of the model. This regulation is based on two independent PID controls which determine the steering angle and the pedals actuation.
If a vehicle is in a trajectory which does not belong to a crossing, and it is located far enough from that crossing, it will be able to overtake if the traffic state in the surroundings allow that. In this case, the vehicle trajectories will be reassigned, as well as the vehicles contained in each one.

These decisions take place every $n$ milliseconds. The smaller this time interval is, the more realistic the simulation can be. However, this decision process takes a great amount of computing resources, mainly when the vehicle is in a crossing neighborhood. For this reason, it will be necessary to reach a compromise solution between realism and computational effort. The behaviour of the driver with regards to signalling are explained in a section below.

### 2.2 Vehicle model

In traffic simulation, kinematic vehicle models have been typically used [3]. However, in this model, in order to give more realism, a dynamic vehicle model has been implemented. This kind of model allows the vehicle to describe slightly different paths depending on its own characteristics as well as its driver’s, whereas a kinematic model forces all vehicles to follow necessarily the same trajectory.

The model used has the 3 basic degrees of freedom:
- Longitudinal movement.
- Lateral movement.
- Yaw angle.

Its main parameters and variables can be seen in figure 2.

The model inputs are the three basic manoeuvres which can be done by the driver:
- Steering angle.
- Gas pedal percentage.
- Brake pedal percentage.

These values are determined by the two PID controls which regulate the vehicle heading angle [1] and longitudinal speed [3].

![Figure 1: Determination of steering and speed reference.](image-url)
2.3 Pedestrian model

The traffic model also includes pedestrian simulation. Pedestrians move along fixed trajectories situated only around crossings. This is done in order to reduce the necessary calculation time, considering that only pedestrians that cross the street are noticeable by the driver of the user vehicle. Pedestrians behaviour is very similar to that implemented for drivers, except for the fact that pedestrians are not allowed to overtake each other. The model used to simulate the movement of pedestrians is based on the vehicle model that is, a dynamic 3 DOF. Certain parameters of the model have been modified to allow the pedestrian to turn around its vertical axis without moving forward.

2.4 Global model

In training simulation is only necessary that the traffic model represents the traffic in a control zone around the user vehicle, figure 3. It is a rectangle positioned around the user vehicle and oriented along its longitudinal axis. The size of the control zones is few hundreds metres around the user vehicle and is determined by the minimum number of vehicles and pedestrian required and by the computer resources.

The user vehicle can be driven by a person or can be compelled to follow a fixed path.

At any time the model tries to maintain the number of vehicles and pedestrians inside the control zone near a total number $n$ fixed by the user. In order to achieve this, the model will detect the vehicles and pedestrians that have gone out the control zone, removing them from the simulation. Besides, it introduces new ones at the intersection points between the trajectories and the control zone. This way of actuation allows a dynamic traffic, as if the whole city was controlled.

Figure 2: 3 DOF vehicle model.
In order to accelerate the calculation of intersection points, the city is divided into sections. The calculations are made only in the sections that have interference with the control zone.

Due to the simultaneous coexistence of the user vehicle, controlled vehicles and pedestrians, the global model must do complex tasks like the prediction of the user vehicle behaviour, the detection of the vehicles and pedestrian that can collide with the other or influence on them and the detection and dissolution of traffic jams.

3 City description

The real geometry of a city, that needs the traffic model, is represented in two dimensions on a CAD drawing. From this map are obtained all data required to describe the city geometry, which are included in the following files:

- Streets file. In this file are included all the data which describe the geometry of a street section. Each section is considered as a list of points with some information associated: point coordinates, vehicles mean speed, etc. This is the main trend in traffic simulators [1],[4]. However, there has been other approaches, like the city division in cantons [2].
- Lanes file. In this file are listed, for every street section, the lanes of which it they are composed. For every lane, it is specified its width as well as its relative direction.
- Nodes file. Here is included the list of all the crossings and roundabouts of the city. Each of them contains a relation of all the possible connections between enter and exit lanes with their respective probability.
4 Signalling

The traffic model considers four types of signals: Give way signals, stops, traffic lights and zebra crossings.

4.1 Give way

The behaviour of a driver when approaching a give way signal depends mainly on its aggressiveness coefficient.

In general, an aggressive driver will not reduce the vehicle speed unless a collision is likely to occur, whereas a moderate driver will slow down the vehicle even if there are not other vehicles in the surroundings of the crossing, and a passive driver will stop the car at the signal as if it were a stop signal.

If a collision is imminent, the driver will stop the car whatever its aggressiveness is.

If there are other vehicles in the surroundings and a collision is possible, the behaviour of the driver is determined by this way:

- Firstly, the possible collision point is determined as the intersection of the paths followed by the cars approaching the crossing.
- The time \( t_1 \) is the time needed by the controlled car to arrive at the signal.
- The time \( t_2 \), which represents the smaller time that any other vehicle needs to arrive at the collision point, is determined assuming that the vehicle speed is constant.
- If the time difference \( t_1 - t_2 \) is smaller than zero but greater than a certain value \( t_3 \) dependant of the driver’s aggressiveness coefficient, the controlled vehicle will stop at the signal.
- If the time difference \( t_1 - t_2 \) is smaller than \( t_3 \) but greater than twice \( t_3 \), the driver will stop at the signal if it is passive, will reduce the speed if it is moderate or will not do anything if it is aggressive.
- In all other cases, the driver will not do anything.

4.2 Stop

The behaviour of a driver when approaching a stop signal is determined in a very similar way than in the case of a give way signal.

As explained before, in general, an aggressive driver will not reduce its speed unless a collision is feasible, while a moderate driver will slow down even if there are not other vehicles in the surroundings of the crossing and a passive driver will stop the car at the signal.

The times \( t_1 \) and \( t_2 \) are the same that in the case of the give way signal. However, depending on the aggressiveness of the driver, its behaviour against the signal differs slightly.
Firstly, if the vehicle is very near the signal and the braking manoeuvre would have to be too hard, the driver will stop the vehicle only if it is a passive or moderate one. On the contrary, it will enter the crossing.

On the other hand, if the time difference $t_1 - t_2$ is smaller than zero but greater than a certain value $t_3$ dependant of the driver’s aggressiveness coefficient, the controlled vehicle will stop at the signal.

In all other cases, the driver will not do anything.

4.3 Traffic lights

The implementation of traffic lights in the model involves two aspects: on the one hand, the simulation of the drivers’ behaviour against the signal and, on the other hand, the regulation of the state of the traffic lights in the city.

4.3.1 Driver behaviour

The driver behaviour against a semaphore depends on the traffic light state and the driver aggressiveness coefficient. It is similar in some ways to the behaviour explained in the cases of the give way and the stop signals.

If the light is green, the driver will not do anything, whatever is its aggressiveness.

If it is red, the driver behaviour depends on the distance to the signal. If the vehicle is far from it, the driver will slow down until the vehicle stops. On the contrary, if it is close to the signal when it turns red, it will stop if it is passive or it will accelerate the vehicle skipping the signal if it is aggressive or moderate.

If the light is yellow, the driver behaviour also depends on the distance to the signal. If the vehicle is closer to the lights than a certain distance the driver will accelerate independently on its aggressiveness. On the contrary, if it is far from the semaphore it will try to stop the vehicle if it is passive or moderate or it will accelerate if it is aggressive.

4.3.2 Traffic lights regulation

The main fact about traffic lights regulation is that the traffic model does not control all the semaphores in the city. Instead, only the traffic lights present in the control zone are controlled.

Traffic lights are controlled in a per crossing basis.

Firstly, the crossings whose lights are going to be regulated are selected. These are all the crossings present on the street on which is located the user vehicle and that are inside the control zone.

For every crossing, the traffic lights which belong to it are the lights at the end of the entering lanes, the ones at the beginning of the outing lanes and the ones at the end of the outing lanes. These last ones are regulated in order to control the traffic leaving the crossing and to foresee the possibility that the user vehicle turns in that direction.

The control algorithm works this way:

- Every crossing has a main semaphore to which the states of all other lights in the crossing are related. This semaphore is the one situated at the end of the street by which the user vehicle would enter the crossing.
- There is also a master semaphore, to which all the main lights of every crossing are related. It is defined as the main semaphore of the first crossing in front of the user vehicle. Its state is calculated as a function of the simulation time. When the user vehicle passes the master semaphore a new master is selected, recalculating his state as a function of the distance to the previous master and a certain mean traffic speed.
- The states of all the main semaphores depend on the state of the master, and are a function of the distance to it and the mean traffic speed.
- In every crossing, the state of the semaphores located at the end of the entering lanes depends on the main semaphore. If they are located in the same street, their states are the same. On the contrary, their states are opposite.
- The state of the semaphores located at the outing lanes is fixed to flashing yellow.

4.4 Zebra crossing

In case that a pedestrian is on the zebra crossing, the driver will stop the vehicle or will reduce its speed until the pedestrian finishes crossing the street.

On the contrary, the driver’s behaviour will be dependant on its aggressiveness. If it is a passive one, it will slow down the vehicle when approaching the zebra crossing. If it is moderate or aggressive, it will maintain the vehicle speed.

5 Manoeuvres and danger situations

The traffic model allows the simulation of some special manoeuvres and danger situations than can occur during a driving session. Depending on the activation method or the objects affected, the model calculates its feasibility and the best chance to execute these manoeuvres and danger situations.

The manoeuvres are carried out by individual vehicles previously selected in the nearby of the user vehicle. Some examples are strong acceleration, hard braking, sudden turn to left or right, abrupt lane change, etc.

The danger situation actions are prepared to take place in the nearby of an area previously selected by the user on the city map. When the user vehicle approaches to the area the action takes place, provided that it is possible and the necessary conditions fulfil. Following are some examples: a vehicle comes out from a garage, a vehicle skips a red light over, the state of a given traffic light is fixed, etc.

6 Applications

Although the model could be used for studies on traffic flow and control, it has been designed for the simulation of near traffic. Its most suitable application is on training vehicle drivers. The type of vehicle, car, van, truck or motorbike, only determines the model of the user vehicle.
Currently, a variant of the model has been implemented on the bus drivers training simulator for the EMT, municipal transport company of Madrid, Spain. The whole simulator is developed by INDRA, the major simulation technology company of Spain, and consist in four training sites. Each site is equipped with four visual channels, 3 DOF movement platform, real reproduction of the hardware of the driver cabin.

A second realisation of the model is being developed in the University for a multi-purpose simulator where can be simulated different type of vehicles like road vehicles, cars, trucks, motorbikes, railway trains, ships and planes. The simulator has a 6 DOF platform with three visual channels mounted on it. Sounds and reactive steering wheel and controls, in conjunction with the movement provide a sensation of very realistic conduction. In figure 4 can be seen some pictures from the simulator and their visual images.

![Figure 4: Pictures from multi-purpose simulator.](image)

### 7 Conclusions

In the paper has been tried to show the most relevant topic that compound the development of a urban traffic model with purposes to be used in simulator. Of course there are more topics to be treated with more deepness, but it will be done in later papers. The fact of its implementation on relevant applications, like the EMT one, indicates that the future of this type of models is beginning. The authors believe in this future and we continue our research to obtain more realistic and suitable traffic models.

### References


